TA No.2193-IND

ASIAN DEVELOPMENT BANK

ENERGY EFFICIENCY SUPPORT PROJECT

SECTOR ANALYSIS
ALUMINIUM INDUSTRY

SUPPORTED BY
GOVERNMENTS OF THE NETHERLANDS AND INDIA

EXECUTING AGENCY
THE INDUSTRIAL CREDIT AND INVESTMENT CORPORATION OF INDIA LIMITED

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April 1996

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Executive Summary

The Government of Netherlands (through the Asian Development Bank) and the Government of India has jointly launched a project titled 'Energy Efficiency Support' (ESP) to look into various aspects of energy and environment issues pertaining to the Indian industry. The project comprises of two distinct phases. Phase-I of the project deals with identification of industry sectors where there is a substantial scope for energy saving and pollution reduction through energy efficiency investments. Phase-II of the project primarily covers various initiatives like undertaking energy and environment audits, feasibility studies, training programmes and promotional campaigns for the industry sectors identified under the phase-I of the study. One of the sectors covered for detailed analysis by TERI under phase-I is the aluminium sector.

The aluminium industry in India is highly concentrated, with just five players accounting for the entire production capacity of 6,10,000 tonnes per annum. Three companies namely HINDALCO, INDAL and MALCO are in private sector and the remaining two, BALCO and NALCO are public sector companies. All these companies have integrated complexes. Invented over 100 years ago, Bayer-Hall-Heroult is the only available commercial technology, even today, for the production of aluminium. For the present analysis, only primary aluminium sector has been selected. The reason being that it is more energy intensive compared to secondary sector and moreover, secondary sector represents a large variety of end products making a focussed study difficult.

Domestic production of aluminium has consistently declined during the last four years from a high of 5.12 lakh tonnes in 1991-92 to 4.29 lakh tonnes in 1994-95. This is partly due to domestic demand remaining same but mainly because of closure of Belgaum smelter unit of INDAL.

The per capita consumption of aluminium in India is 0.5 kg only as against the World's average of 5 kg. With demand expected to grow by about 9 percent from present consumption levels, even 100 percent utilization of existing capacity will not be sufficient to bridge the demand-supply gap in future. There is a fear that India, which is a net exporter of aluminium for some years, will become net importer by the turn of this century, if further capacities are not added. All the aluminium producers have plans for modernisation and expansion of existing smelters and also for greenfield projects.

Electricity, coal and fuel oil are the major forms of energy used by the sector with electricity accounting for 50% of the total energy use. Overall, energy accounts for nearly 40% of total cost of aluminium production. Based on 1994-95 figures, total energy

consumed by all primary producers in the country is estimated to be 30.1 Gcal, when all the energy forms are converted to primary sources.

Energy consumption in aluminium production varies from plant to plant depending on the vintage. In India, all primary aluminium producers have set up their smelters based on different design parameters adopted at that time by their foreign know-how suppliers. NALCO has introduced the latest energy efficient systems and has the lowest specific energy consumption of 13,700 kWh per tonne of aluminium production. The remaining plants are operating at specific energy level in the range of 15,000 to 18,100 kWh per tonne of aluminium. Although Indian plants have taken a number of initiatives to improve energy efficiency but there is scope for further improvement in energy consumption, so that it can be brought down to 13,500 kWh per tonne prevailing in some of the plants elsewhere in the world.

Aluminium production is a highly energy intensive process and provides lot of scope for energy conservation. Almost all the operations require modernisation and\or modifications. A co-ordinated approach on all fronts would enable energy saving in the range of 15-20% of the total energy use. The major technological developments which could lead to significant reduction in the energy consumption in the aluminium production are given below:

- Replacement of rotary kiln by Gas Suspension Calciner.
- Adoption of tube digestion system.
- Implementation of better agitation techniques.
- Use of large size filters and additives.
- Installation of plate heat exchangers.
- Auto-control of process parameters.
- Various energy saving options in smelters.

Considerable research and development efforts are being carried out to improve the worldwide accepted Hall-Heroult technology and also to find an alternative process route which is less energy intensive and less costly for aluminium production. Several organisations in the world are experimenting with these processes and have claimed significant advantages over the conventional Hall-Heroult process. However, these processes are either in the laboratory stage or under pilot operation and are not yet commercially established.

Aluminium production is basically polluting in nature. Almost all types of pollution i.e., gaseous ,solid and liquid effluents and wastes from different stages of aluminium production takes place. The major pollutants released during smelting are the gaseous and particulate fluoride emissions. Most of the Indian plants have provided gas

cleaning installations like wet scrubbing or dry scrubbing systems to clean the cell gases before release to the atmosphere through stack. Except for two plants, all other plants comply with the pollution control standards specified by pollution control board of respective states.

Based on the assessment of this sector and its comparative evaluation with other sectors covered under the study for phase-I, this sector is not recommended for selection for the phase-II of ESP.

CHAPTER 1

Introduction

The Government of Netherlands (through the Asian Development Bank) and the Government of India has jointly launched a project entitled 'Energy Efficiency Support Project (ESP)' to look into various aspects of energy and environmental issues pertaining to the Indian industry. The project comprises of two distinct phases. Phase-I of the project deals with identification of industry sectors where there is a substantial scope for energy saving and pollution reduction through energy efficiency investments. Phase-II of the project primarily covers various initiatives like undertaking energy and environmental audits, feasibility studies, training programmes and promotional campaigns for industry sectors identified under the phase-I of the study. One of the sectors covered for detailed analysis by TERI under phase-I is the aluminium sector.

Aluminium is the most widely used metal in the modern society. The versatility of aluminium is evident from the fact that it can be alloyed, anodized, wrought, welded, cast, clad and recycled for a variety of end use applications. The phenomenal growth of this comparatively newcomer to the family of metals is due to its multi-dimensional characteristics i.e. resistance to corrosion, high strength to weight ratio, attractive finish, good conductivity, high density, good cryogenic properties and absence of toxicity.

The aluminium industry can be divided into two sections - primary metal producers and secondary fabrication units. In the primary sector, aluminium is manufactured from bauxite while in the secondary sector it is further processed into rolled products, foils, extrusions and properzi rods. In this report, a review of the primary aluminium industry is attempted. The secondary sector is left out as it is much less energy intensive compared to primary sector and represents a large variety of end products (many of which are manufactured in un-organised sector) making a focussed study impossible.

CHAPTER 2

Sector Profile

2.1 Overview of Aluminium industry

The aluminium industry in India had a humble beginning in 1943 when Alcan floated an Indian subsidiary, Indian Aluminium Company (INDAL), to set up an aluminium sheet cold-rolling mill at Belur (West Bengal). The first aluminium smelter of the country was commissioned in 1962. Located at Renukoot (Uttar Pradesh), the smelter was established by HINDALCO with technical support from Kaiser Aluminium of the USA. Last aluminium plant to be set up in private sector was Madras Aluminium Company (MALCO) in the year 1964.

Thereafter state-owned Bharat Aluminium Co. (BALCO) was set up in 1965 at Korba (Madhya Pradesh) to make primary metal and fabricated products. In 1988, the National Aluminium Co. (NALCO) in public sector was set up with a smelter capacity of 2,20,000 tonnes per annum (tpa), emerging as the country's largest producer and exporter of aluminium.

All the aluminium smelters in the country are based on foreign technological know-how. The source of foreign know-how linkage with their year of commissioning and location is indicated in **table 2.1**.

Table 2.1. Aluminium companies in India - a profile

S.No	Company	Location	Year of commissioning	Technology supplier
1	INDAL	Alupuram (Kerala)	1943	Alcan Aluminium
2	HINDALCO	Renukoot (U.P.)	1962	Kaiser Aluminium,
3	MALCO	Mettur (T.N.)	1964	Montecatini, Italy
4	BALCO	Korba (M.P.)	1975	VAMI, USSR
5	NALCO	Angul (Orissa)	1987	Aluminium Pechini, France

2.2 Production

The aluminium industry is highly concentrated, with just five players accounting for the entire capacity. Out of this, HINDALCO and NALCO together control the supply of almost 70 percent of primary metal that comes into domestic market. Present installed capacities and production of aluminium in the country since 1991-92 is provided in **table 2.2** for each of the five plants.

Table 2.2. Pattern of aluminium production

Company	Capacity (lakh tonne)	Production (lakh tonnes) 1991-92	1992-93	1993-94	1994-95
INDAL	1.17	0.62	0.39	0.30	0.45
BALCO	1.00	0.92	0.91	0.92	0.93
NALCO	2.18	1.92	1.91	1.94	1.29
HINDALCO	1.50	1.66	1.62	1.54	1.64
MALCO *	0.25	-	-	-	-
Total	6.10	5.12	4.83	4.70	4.29

MALCO had suspended production since April 1991 because the production of aluminium was not financially viable. The company submitted two revival proposals and also envisaged the export of aluminium as a part of the resuscitation strategy. Following the takeover by Sterlite Industries, the plant has restarted operations this year.

The domestic production of aluminium has consistently declined during the last four years. From a high of 5.12 lakh tonnes in 1991-92 the present production level has declined to 4.29 lakh tonnes. But this decline was not because of a drop in demand - as is evident from the consistent production levels achieved by HINDALCO and BALCO - but owing to operational problems.

In fact, while HINDALCO has managed to operate at more than 100 percent capacity utilisation, BALCO is operating at almost 90 percent capacity consistently. Aluminium production fell drastically in 1992-93 to 4.83 lakh tonnes from 5.12 lakh tonnes the previous year, primarily due to closure of INDAL's Belgaum smelter.

Major constraints in achieving higher capacity utilisation is inadequate/interrupted electric power supply to aluminium smelters in India. The uncertain power supply not only results in heavy production loss, but also increased specific consumption of various costly input materials. To overcome this problem, all aluminium producers have installed their own captive power plants except Indal. Hindalco and Nalco have installed their own captive power plants of 350 MW and 720 MW capacity respectively to get uninterrupted power supply at lower cost. In fact, the power cost, today, has become the key determinant in the production of aluminium. Power from a captive power source costs Rs 1 per unit against Rs 2.20 to Rs 3.50 per unit when procured from government bodies like SEB's. Indal is a classic example of how power costs could shift the fortunes of the industry. Indal preferred to keep its 75,000 tonnes smelter at Belgaum closed down from middle of 1992 to the end of 1994, since high power cost from SEB of Karnataka made the production of basic metal an unviable proposition, compared to procuring it from outside, for value-addition at its complex. It has started partial production in December 1994 after prices of the aluminium metal started rising and production became financially viable.

2.3 Consumption and demand

The per capita consumption of aluminium in India is 0.5 kg as against 25 kg in USA, 19 kg in Japan and 10 kg in Europe. Even the world's average per capita consumption is about ten times of that in India.

Aluminium has two well defined sets of uses. The first refers to the set which groups all electrical applications. These applications require a specific grade of aluminium generally referred to as E.C. grade. The other set includes all non-electrical applications and the metal required is called Commercial Grade (C.G.) aluminium. Although there is no significant difference in the purity composition of the two grades of aluminium, the E.C. grade metal can be used for non-electrical applications while the C.G. grade can not be used for electrical application.

The pattern of consumption of aluminium in India is vastly different from that of developed countries. End use of aluminium in the India vis-a-vis the World in different sectors is indicated in **table 2.3**.

Table 2.3. End use of aluminium - A comparison

Sector	India (%)	World (%)
Electrical	35	8
Transport	18	29
Construction	6	19
Packaging	7	20
Consumer durables	34	24
Total	100	100

Source : Industry watch/Aluminium - Smelting a boom, Business Today, September 22-October 6, 1995.

Considerable potential exists in the country for enhanced growth of aluminium usage in transport, building and construction as well as canning and packaging sectors.

Table 2.4 exhibits the aluminium production, import, export and availability since 1980-81.

Table 2.4. Trend of Aluminium availability ('000 MT)

Year	Production	Import	Export	Net Availability
1980-81	199.02	124.08	4.32	318.78
1985-86	264.83	69.74	2.75	331.82
1988-89	357.35	60.00	20.00	397.35
1990-91	449.38	12.60	35.44	426.54
1991-92	512.33	9.08	73.00	448.41

Source : Minerals and metals review, August 1992/93.

The demand for primary aluminium in the year 1999-2000 and 2004-05, as estimated by the Working Group on non-Ferrous Metals for the Eighth Plan is given in **table 2.5**.

Table 2.5. Demand projections for aluminium ('000 t)

Year	EC grade	CG grade	Total
1999-00	269	558	827
2004-05	348	812	1160

Source: Working Group for Non-Ferrous Metals report of Sub-group on aluminium, Magnesium, etc. for Eighth Plan.

The current installed capacity of aluminium at about 610,000 tonnes per annum (tpa) will go up to 650,000 tpa in next two years with expansion currently on in the existing plants. The industry is presently operating at an average capacity utilisation of 70 percent. With demand expected to grow by about 9 percent per annum from present levels, even 100 percent utilisation of existing capacity will not be sufficient to bridge the gap between demand and supply in future. There is a need to take up modernisation and further expansion of existing smelters and possibly setting up of new aluminium plants in the country.

2.4 Expansion plans of the industry

In recent years, the domestic aluminium industry has experienced steady fortunes charaterised by balanced demand and absence of any discernible shortfalls. Coupled with a growth in domestic demand, high prices and reduction of excise duties helped Indian aluminium companies to surge ahead with hopes of sustained growth in future years. Almost all the domestic aluminium producers have ambitious expansion and modernisation plans.

HINDALCO plans to invest Rs 1750 crores over the next two years in raising its smelting capacity to 2.10 lakh tpa and then further increasing it to 2.42 lakh tpa. Simultaneously, in order to match the planned increase in smelter capacity, alumina capacity will be increased from 3,50,000 tpa to 4,50,000 tpa. Besides the expansion -cum-modernisation at the existing plant, HINDALCO is also planning to set up a integrated aluminium plant in Orissa, costing Rs 5000 crore. The new plant will be able to produce 5 lakh tonnes of alumina and 2.5 lakh tonnes of aluminium in a year. As a part of the project, the company also plans to set up an 800 MW thermal power plant to generate power for captive consumption.

INDAL is aiming to go in for increased backward integration and simultaneously move further down the chain of value-addition. It plans to add another additional 10,000 tonnes smelting capacity to its total production. INDAL is setting up a one million tonne

per annum 100% export oriented alumina plant in Koraput, Orissa in collaboration with Tatas and Norsk Hydro of Norway with an estimated investment of Rs 2,400 crore.

NALCO has planned to expand its alumina capacity to 1.35 million tonnes from 8 lakh tonnes at present and expand the capacity of its bauxite mines from 2.4 million to 4.8 million tonnes. This will cost around 12.1 billion rupees. Also the company plans to increase its aluminium smelter capacity to 3,45,000 tonnes from 2,18,000 tonnes per annum at present and step up its captive power plant to 960 MW from 720 MW. NALCO is also planning to set up two joint ventures with the United Arab Emirates (UAE) at a total cost of Rs 4,400 crore for a one million tonne alumina refinery in either Andhra or Orissa (Rs 2,500 crore) and a 1.25 lakh tpa smelter (Rs 1,900 crore) in the UAE.

BALCO has laid more emphasis on value-addition rather than production of basic metal. It plans to manufacture aluminium cans and containers, a power unit, a super purity aluminium plant and modernisation of existing foundry.

MALCO has very recently commenced production after being taken over by Sterlite group. It has plans to increase its alumina capacity to 80,000 tpa from 50,000 tpa at present and modify its smelter.

2.5 Technology Status

2.5.1 Manufacturing process

Alumina is the basic raw material for the production of aluminium through elctrolytic process. The production of alumina obtained from bauxite, a mineral containing upto 60% in the form of mono/trihydrate is carried out through the Bayer route which is an extractive hydro-metallurgical process. This process was invented in 1888 by Karl Joseph Bayer of Austria and is still the most economical process for extraction of alumina from bauxite. In 100 years of its existence, considerable modifications/improvements have taken place in the Bayer process with regard to efficiency improvement of the various operations, pollution reduction and optimisation of production cost.

Production of aluminium is based on worldwide accepted Hall-Heroult technology which though invented over 100 years ago is the only available commercial technology even today. In this process, aluminium metal is produced through the electrolytic reduction of calcined alumina.

Technologies employed and different steps involved in the production of alumina and aluminium metal are explained below.

2.5.1.1 Alumina (Bayer's process)

Production of alumina basically involves elimination of impurities like iron oxide, titanium dioxide, silica and others from various alumina bearing raw materials so as to extract product of high purity for its subsequent reduction to aluminium metal. Although the research on alumina production from various raw materials and different process routes has continued for many years, World's major production of electrolytic grade alumina is through the conventional Bayer process. Typical flow sheet of Bayer's process showing the material and energy requirement is shown in **figure 1**.

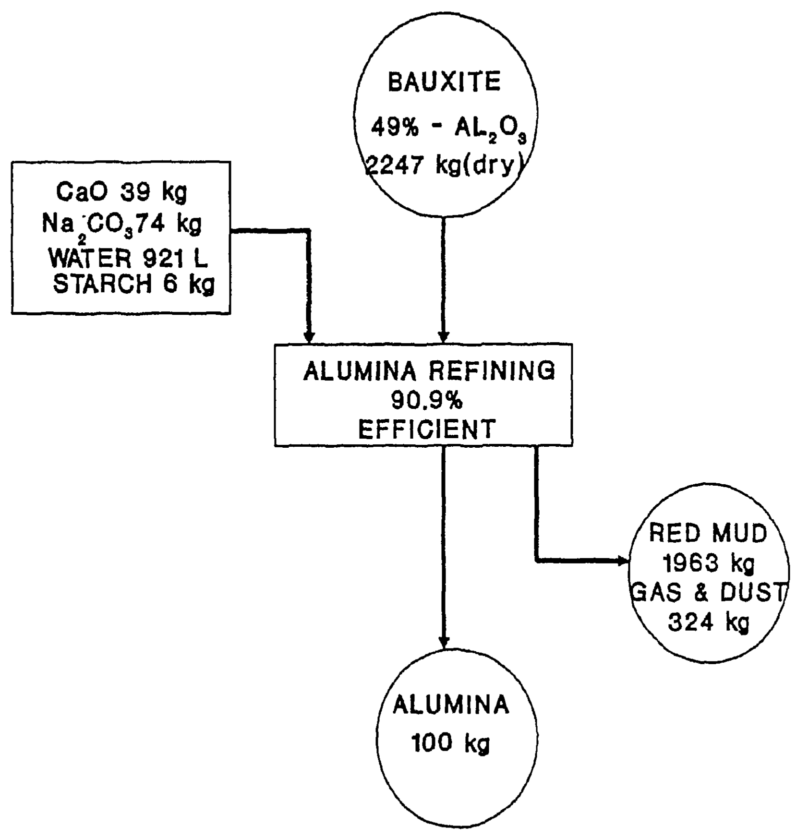


FIG. 1: MATERIAL BALANCE FOR THE PRODUCTION OF ONE TONNE OF ALUMINA (TYPICAL)

Unit operations of the Bayer process can be classified under following two broad heads:

- Red Section
- White Section

Some selected details of different unit operations are discussed below.

A. Red section

mines is usually 100 to 200 mm and is required to be crushed before grinding. Bauxite is ground and slurried in spent liquor to produce slurry of desired concentration and particle size distribution. Rod/ball mills in combination with various types of screens are used. Type of mill depends on the hardness of bauxite to be ground.

b. **Desilication**. The bauxite slurry is pumped to large desilication tanks where the slurry is heated to around 95^0 C with a retention time of 8 to 10 hours. This process reduces the scale formation in digestion equipment.

c. **Digestion**. During digestion aluminium hydroxide is extracted from bauxite at optimum efficiency. The conditions, type of equipment and mode of operation are different depending on type of bauxite.

Predominantly monohydrate bauxites (Boehmite and Diaspore) need high temperature and high concentrations while trihydratic bauxite (Gibbsite) requires low temperature and concentration of caustic soda for dissolution.

Bauxite slurry is pumped at high pressure through preheaters to the autoclaves where the slurry is further heated to attain the digestion temperature. The heating may be direct or indirect with steam. The digested slurry in case of high temperature/pressure digestion is flashed down to atmospheric pressure in flash tanks. During flashing steam is generated which is used in the process to optimise the overall heat economy. The slurry after flashing is diluted and pumped to settling and washing area.

In Indian alumina plants, generally high pressure/temperature digestion has been adopted except in NALCO plant where digestion is carried out at atmospheric pressure.

d. **Mud separation, washing and disposal**. The digested slurry is separated into liquid and solid phases in a counter current decantation (CCD) system. Molar ratio of the slurry is also adjusted prior to CCD. The slurry is fed to thickeners where flocculent is added to enhance the settling of the red mud and clarification of the liquor. The overflow is pumped to control filteration unit in white area, while the mud is thickened and washed to recover soluble values. The washed mud is pumped to mud storage/disposal pond. In most cases, the liquid phase is recycled from red mud pond to the process stream.

B White section

a. Control filteration. This operation ensures that the product specifications are met by removing the suspended mud particles from the decanted aluminate liquor. Pressure filters are the main equipment with paper pulp/lime slurry as a filter aid. The clarified liquor is sent for precipitation.

b. Precipitation. The clarified aluminate liquor is cooled either by heat exchangers or by flashing. Seed hydrate is repulped with part of aluminate liquor and charged to precipitation tanks. Precipitation is a crystallisation process in which the aluminate anion hydrolyses and grows at the surface of the hydrate crystal. Depending on the physical properties of the alumina required, precipitation conditions are controlled which include temperature, seed ratio, stirring method, retention time, etc. Precipitation time varies from 30 to 75 hours with inlet temperature ranging from 50 to 85^0 C. Slurry from precipitation is pumped to hydrate classification unit. Precipitation may be a continuous or batch process. Both systems are employed in Indian alumina plants.

c. Hydrate classification. The underlying principle is gravity sedimentation. Depending on whether the plant produces sandy, floury or intermediate type of alumina, classification may or may not be necessary.

In a sandy alumina plant, a fraction of the coarse hydrate is also used as seed, along with the bulk of fines. Most classification circuits consist of a primary, secondary and tertiary set of thickeners. The spent liquor from precipitation is sent to evaporation, grinding and desilication sections and the product hydrate is filtered and washed to remove the impurities in drum/pan/disc filters. Indian alumina plants are producing sandy as well as floury/intermediate type of alumina. Therefore, various types of classification systems exist in Indian plants.

d. Calcination. Free moisture and water of crystallisation is removed in this operation and alumina hydrate is reduced to anhydrous alumina. Temperature of calcination varies from 1000 to 1200^0 C. The calcined alumina is a white powder of either floury or sandy consistency. Present trend is towards production of sandy alumina which is preferred due to adoption of effective pollution control systems in smelters known as dry scrubbing. Calcination unit is a major consumer of energy and mostly uses low sulphur furnace oil. The equipment used may be oil or gas fired rotary kilns or fluid bed calciners.

e. **Evaporation and By-products recovery.** This unit operation helps in maintaining the water balance and concentration of circulating liquor required in the plant. Part of the spent liquor after precipitation is diverted for evaporation. Under this process, liquor is heated to a preset temperature with the help of flashed and live steam. The heated liquor is then allowed to flash in vessels resulting in concentration of liquor. Usually, shell and tube type heat exchangers are used in the process. In the course of time, organic impurities build up in the liquor in the form of oxalates, vanadates, soda salt etc. These are required to be removed to enhance the liquor productivity. Out of the various by-products, vanadium sludge has economic value and is utilized for production of vanadium pentoxide. Gallium is other valuable by-product from the alumina plants.

2.5.1.2 Aluminium Production (Hall-Heroult's process)

The Hall-Heroult process is employed for the production of aluminium through electrolysis of alumina dissolved in fused electrolyte which is a chemical mixture of sodium fluoride (NaF) and aluminium fluoride. Cryolite bath at operating temperature ranging from 920 to 970^0 C dissolves upto about 10% alumina. Under the influence of high intensity direct current (D.C.), alumina which is an oxide of aluminium gets dissociated to aluminium and oxygen ions in the electrolytic cell. Aluminium ions having positive charge deposit at the cathode and oxygen ions go to anode and form CO_2 and CO, depending upon the operating conditions. Gases evolved are taken to gas cleaning plant for treatment. Molten metal is tapped from electrolytic cells and cast into ingots in the ingot casting plant. Typical flow sheet of Hall-Heroult process showing the material and energy requirement is shown in **figure 2**.

The major technological facilities required for production of aluminium are explained in this section.

A. Electronic cell houses

Number of electrolytic cells connected together in series are housed in buildings which are termed as electrolytic cell houses. Two types of anode systems are employed in the cells. These are continuous self baking or Soderberg system and pre-baked system. In the Soderberg system, anode is baked by reaction heat from the electrolytic cell as it is continuously lowered into the electrolytic bath. The carbon paste forming the anode is fed into the top of the anode casing so that a single large anode for the entire anode system is formed. In the pre-baked system, anode blocks are produced separately and baked before use. A number of these anode blocks are suspended vertically from anode bus-bars above the electrolytic cell.

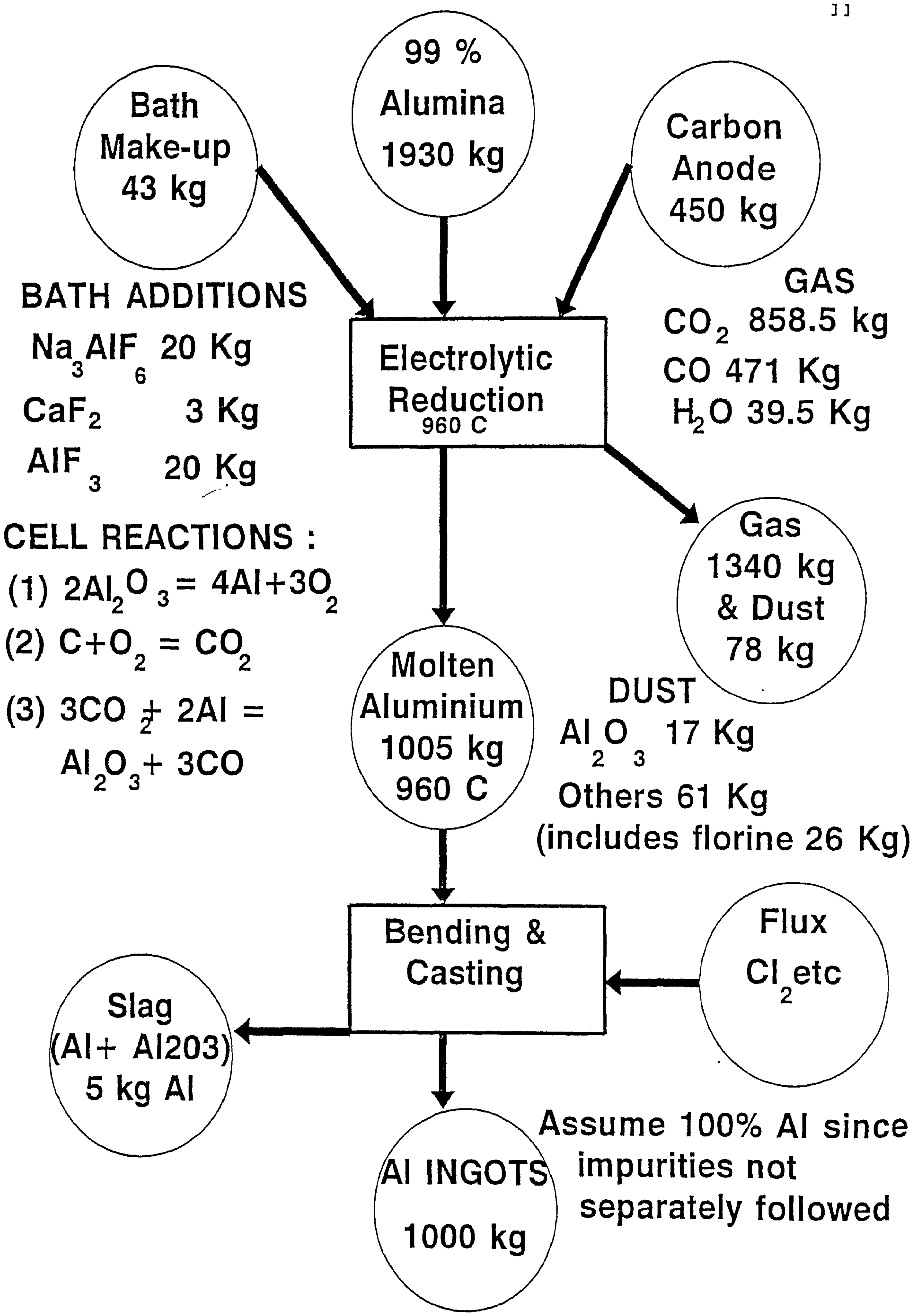


Fig. 2: HALL-HEROULT PROCESS FOR PRODUCING ONE TONNE OF ALUMINIUM FROM ALUMINA (Typical)

B. Gas cleaning facilities

The electrolytic process for production of aluminium gives rise to the liberation of hydrogen fluoride by dissociation of fluorine salts in the bath and burning of carbon anodes contributes to the emission of carbon monoxide, carbon dioxide and resin distillates like tar and other harmful species. Gases liberated during electrolysis process also contain sulphur dioxide and alumina dust. Release of the liberated gases without treatment into the atmosphere is not favoured since these gases are harmful to vegetation. Furthermore, the gases have a fair concentration of fluorides which can be recovered. Two types of gas cleaning processes are in use, namely;

(i) Wet scrubbing process

(ii) Dry scrubbing process

C. Cryolite regeneration facilities

Cryolite regeneration facilities are provided to recover cryolite from the exhaust gases of the electrolytic reduction cells for re-use alongwith fresh cryolite for the electrolytic operation.

D. Anode carbon plant

Depending upon the anode system adopted, the following facilities are required in anode carbon plant.

(i) Anode paste preparation

(ii) Anode forming

(iii) Anode baking

(iv) Anode rodding

2.5.1.3 New processing technologies

Some of the processes which have shown encouraging results and may be commercially feasible in future are named here under :

(i) Alcoa process

(ii) Carbothermic process

(iii) Toth process

(iv) Kuwahara process

These processes have been explained in detail in para 4.8 under the heading " New energy efficient technologies".

CHAPTER 3

Energy profile

3.1 Fuel sources

The energy cost both for thermal and electrical energy, represents nearly 40% of the total cost of aluminium production. Primary energy inputs are electricity, coal and fuel oil. Electricity is the major energy input in aluminium production and is considered to be a prime factor in determining economics of aluminium production. It has a share of 30% in the total cost of production. In India, the average specific electricity consumption in smelters is around 16,500 kWh/MT of aluminium. Coal and fuel oil (including LSHS and HSD) are consumed in alumina refining process. Coal is primarily used to generate steam which is used in the process while fuel oil is used mainly in calcination of alumina. In a typical medium level alumina plant, energy distribution among different process stages is shown in **figure 3**.

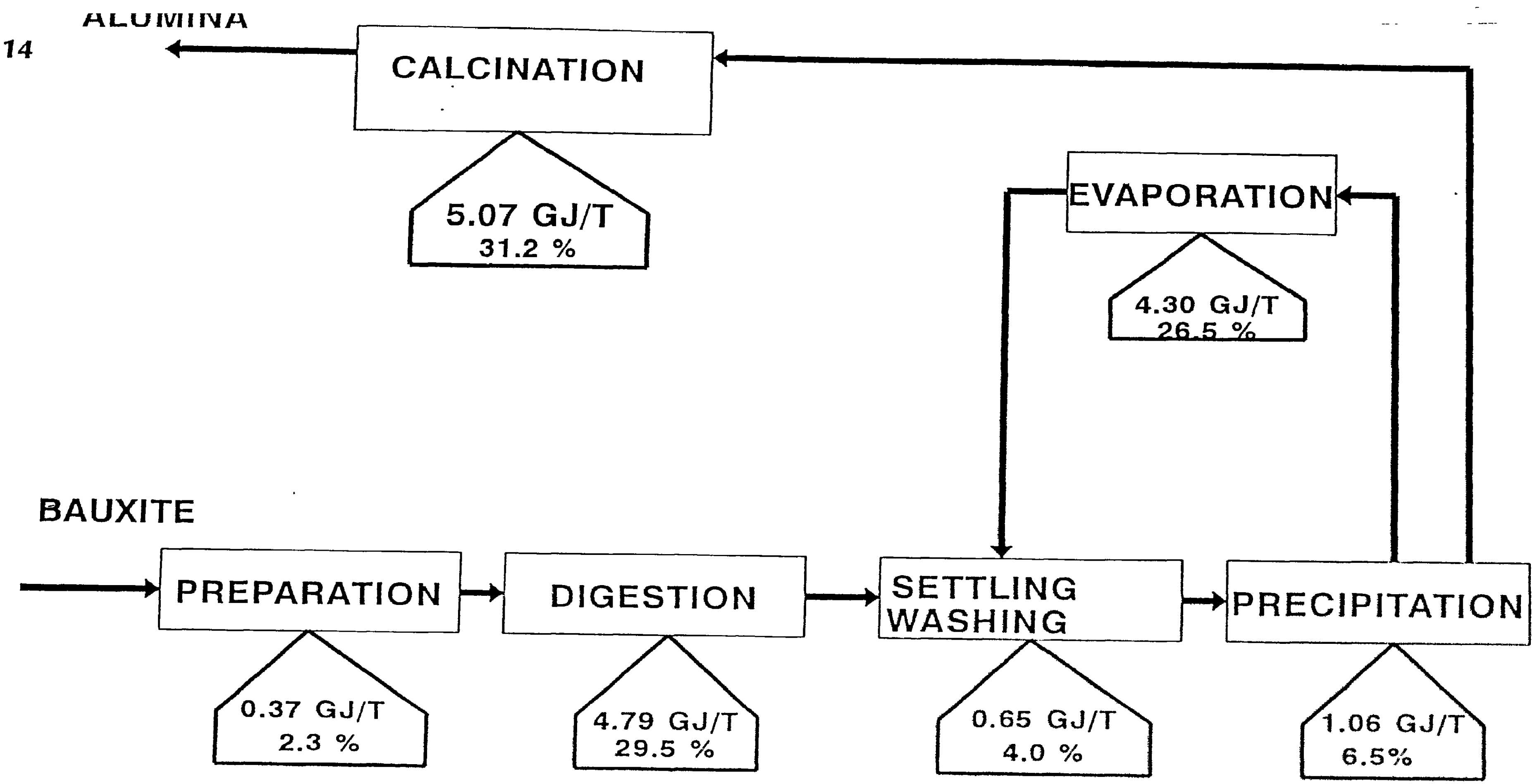
The most important raw material used in smelting process for aluminium production is calcined petroleum coke (CPC), accounting for 15% of the cost of production. CPC is imported since indigenous production of CPC is not sufficient to meet the requirements of aluminium industry in India.

3.2 Energy consumption in the secto

The absolute consumption of different forms of energy in the aluminium sector is; (i) 720 million kWh for electricity, (ii) 24 million tonne of coal and (iii) 13 million kg of fuel oil. If the electricity consumption is converted to its equivalent primary energy source, i.e., coal, the total energy consumption in the sector works out to around 30.1 Gcal. Electricity is the major form of energy used in the sector as can be seen from **figure 4**, which shows the relative share of different forms to produce one tonne of aluminium from bauxite.

3.3 Specific energy consumption norms

Energy consumption in aluminium production varies from plant to plant depending on the technology adopted. In India, all primary aluminium producers have set up their smelters based on different design parameters adopted at that time by their foreign know-how suppliers. Design norms as well as actual values of specific energy consumption for all the four operating aluminium plants in the country are given in **table 3.1.**



TOTAL ENERGY INPUT : 16.24 GJ/T, 100%

FIG. 3 : DISTRIBUTION OF ENERGY CONSUMPTION IN A MEDIUM LEVEL ALUMINA PLANT AMONG THE PROCESS STAGES

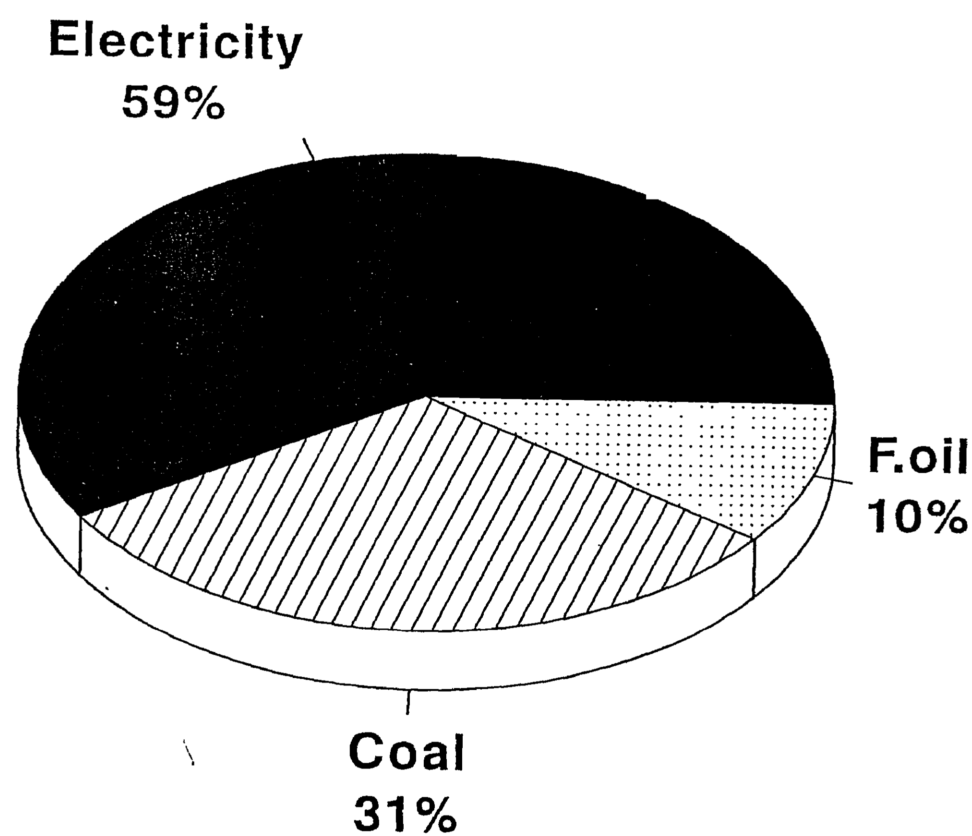


Fig. 4: Share of different energy forms in aluminium production

It will be observed that all Indian plants except NALCO have been designed to operate at power consumption ranging from 16,000 to 18,000 DC-kWh per tonne of aluminium. NALCO has introduced the current energy efficient technology with DC power consumption of 13,742 kWH per tonne of aluminium.

Table 3.1. Specific energy consumption - design norms

Company	Alumina plant			Smelter
	Steam (T/T)	Fuel oil (kg/T)	Power (kWh/T)	(DC-kWh/T)
HINDALCO	4.17	78.0	360	18,000
BALCO	3.28	126.0	437	16,020
INDAL				
- Belgaum	2.31	244.0	232	18,500
- Muri	5.86	105.0	312	18,500
NALCO	3.11	85.3	380	13,742

In order to assess the performance of primary aluminium producers in the country, actual specific energy consumption figures of these plants were analysed. Plant-wise data on specific energy consumption are given in **table 3.2**. The data for the best operating aluminium plant elsewhere in the world are also given for comparison.

It can be seen from table 3.2 that energy consumption in the Indian plants is much higher than that being achieved abroad. Even among the Indian producers there is wide fluctuation in terms of specific energy consumption. INDAL has been able to achieve the best results in steam consumption (due to low caustic concentration and low pressure digestion), NALCO and HINDALCO in fuel oil consumption (Gas suspension calciner/Fluidised bed calciner) at alumina plant, NALCO in electricity for smelting.

Table 3.2. Specific energy consumption - actual performance

Company	Alumina plant			Smelter (kWh/T)
	Steam (T/T)	Fuel oil (kg/T)	Power (kWh/T)	
HINDALCO	5.0	85	385	15,000
BALCO	3.5	101	529	18,100
INDAL *				
- Belgaum	2.4	220	250	17,000
NALCO	3.2	85	380	13,700
Best operating plant	2.4	80	240	13,500

* Muri plant data not available.

Source:

1. Energy conservation in the production of Alumina and Aluminium - H. Mahadevan and T.R. Ramachandran
2. Questionnaire from BALCO (1994-95)

CHAPTER 4

Energy conservation opportunities

Aluminium production being a highly energy intensive process provides a lot of opportunity for energy conservation. Almost all the operations require modernisation and/or modifications. A co-ordinated approach on all fronts would enable reduction in the range of 15-20% on the energy requirements. This together with the improved and efficient performance of the energy producers, can contribute to a reduction in production cost of about Rs 3000-4000 per tonne of metal. The major developments which could lead to significant reduction in the energy consumption levels in the aluminium industry are discussed below.

4.1 Replacement of rotary kiln by Gas Suspension Calciner

Most of the present alumina plants have rotary kilns for calcination of hydrate alumina which require about 100-130 kg of fuel oil to calcine one tonne of alumina. Energy efficient Fluid bed calciner with specific consumption of about 85 kg of fuel require less maintenance and produce better quality of alumina. This system is recommended for adoption in alumina plants. Other efficient systems viz. Gas Suspension Calciner (GSC) may also be considered. NALCO has adopted fluid bed calciner and HINDALCO has adopted Gas Suspension Calciners (GSC) with success.

4.2 Adoption of tube digestion system

All the Indian alumina plants except NALCO are using conventional digestion system adopting autoclaves with either direct steam heating or indirect heating by passing steam through coils. Direct injection of steam results in loss of condensate and dilution of plant liquor. Tube digestion has been adopted in alumina plants in Hungary and West Germany. This is an efficient system for dissolution of particularly monohydratic bauxites, with low maintenance and thermal requirement as compared to conventional system. This system will result in lot of energy saving at the alumina refining stage.

4.3 Implementation of better agitation techniques

Precipitation process, to produce coarse alumina, can now be carried out at high concentration and high temperature. This reduces requirement of evaporation of liquor and increases liquor productivity and consequently calls for lower energy requirement. Wherever applicable, this precipitation technique may be adopted. Incorporation of

improved air agitation or mechanical agitation will reduce power requirement in Indian plants.

4.4 Use of large size filters and additives

Use of large size disc and drum filters for filteration of seed and product hydrate is the latest trend on account of higher specific output. This aspect may be kept in view while planning revamping/modernisation of old plants.

In order to reduce adhesive moisture in the filtered hydrate, use of additive is practised. This results in lower energy requirement at calcination stage. This practice can be adopted in Indian plants for conservation of energy.

4.5 Installation of plate heat exchangers

Plate Heat Exchangers (PHE) should be used to cool aluminate liquor coming from control filteration area. BALCO and NALCO have provided the same in their plants. Use of Plate Heat Exchangers will save thermal energy in other Indian aluminium plants also.

4.6 Auto-control of process parameters

Nowadays auto control of process by use of computer is well established. Better process control results in lower energy consumption and raw materials and better quality control. Pneumatic and electronic instruments of sophisticated nature are in use for the process control the world over. Installation of Programmable logic Controller (PLC) in the cell houses will help in reducing electrical energy consumption in smelters. HINDALCO has installed PLC for their smelters and achieved a reduction of 3% in specific energy consumption.

4.7 Energy saving options in smelters

All the aluminium plants in the country are based on the state of technological innovation in vogue at the time they were conceived. Thus it can be seen that gap in technology adopted with the current advancements would be directly in line with the age of the plant unless plant modernisation and revamping had been taken as an ongoing continuous programme. Indian aluminium industry has evolved its own modernisation and revamping programme for technological development within the framework of resource constraints both technological and others. In general, there is considerable scope for improving the technological level (except NALCO). All these measures will not only save huge amount of energy but will substantially reduce the cost of production and improve the bottomline of these companies. Some of the areas identified are as follows:

(i) Provision for mechanised and automatic alumina feeding facilities.

(ii) Automation and mechanisation of cell operation by introducing microprocessor and computer.

(iii) Improvement in cathode lining and cell design.

(iv) Improvement in anode design, possibility of increasing anode areas by redesigning the existing cell.

(v) Provision for efficient gas cleaning and recovery of fluorides by dry scrubbing system.

4.8 New energy efficient technologies

Considerable research and development efforts are being made to improve the worldwide accepted Hall-Heroult technology and also to find out an alternative process route which is less energy intensive and less costly for aluminium production. At present several organisations in the world are experimenting with new reduction processes and have claimed significant advantages over the conventional Hall-Heroult process. However, these processes are either in the laboratory stage or under pilot operation and are not yet commercially established.

Promising among them are discussed below.

4.8.1 ALCOA Process

Aluminium Company of America (ALCOA) has patented a process whereby alumina is chlorinated in areactor to convert the oxide to chloride. The chloride is thereafter electrolytically processed in an entirely closed cell which dissociates the aluminium chloride to molten aluminium and chlorine which is continuously recycled back to the reactor in a closed loop. The process will help to reduce power consumption by as much as 30% and occupies a relatively much smaller plant area in comparison to the Hall-Heroult process. Also no emissions will take place since it has a closed cell system. Also, capital and operating costs will be lowered. A pilot plant set up under this process in Palestine in Texus was closed down due to severe corrosion of the hardware.

4.8.2 Carbothermic process

This process produces aluminium by reducing alumina with carbon. Pure alumina or an aluminous ore is used as raw material. The aluminium carbide produced in the process is decomposed at about 2100 C and reduced to aluminium below atmospheric pressure. The process is being developed by Aluminium Pechiney of France.

4.8.3 Toth Process

The Toth process is being promoted by the Applied Aluminium Research Corporation, USA. It is claimed that this process permits the projects cost to be reduced by 50 to 7(production cost of aluminium to be reduced by 50%, reduction in electrical power consumption by 90% and elimination of pollution problems associated with the conventional process. The use of bauxite as raw material is eliminated permitting the use of clay and other aluminous ores. In this process, calcined clay is fed to the fluidised bed reactor where chlorination takes place with chlorine gas. Aluminium chloride produced is reduced to aluminium by manganese. The process, still at the pilot plant semi-commercial stage, would require more time to fully attain commercial status.

4.8.4 Kuwahara Process

The Kuwahara process for production of aluminium is basically a carbothermic process developed in Japan. In this process low grade bauxite or clay containing about 35% alumina and coal are ground to powder which is briquetted. The briquettes are heated to 600-900 C in a coking furnace under inert gas. The coked briquettes are fed to a blast furnace and heated to about 2000 C by electric arc. This produces a crude aluminium alloy containing 60% aluminium and 40% Fe, Si and Ti. At the bottom of the blast furnace, molten lead is spray-splashed in to the crude alloy at about 1200 C. This produces an aluminium-lead alloy, separating out the Fe-Si-Ti. The Al-Pb alloy is transferred to a liquation pot. On standing in the molten state, aluminium separates out at the top and lead sinks to the bottom. After purification in fractional vacuum distillation vessel, aluminium metal of 99.9% purity is obtained. It is estimated that electric power consumption will be reduced from 15,000 kWh/t (Japanese Bayer-Hall) to about 5000 kWh/t. Manpower requirement is only about one third that of BHH process.

CHAPTER 5

Environmental aspects

5.1 Type of pollution and major pollutants

Environmental hazards due to aluminium industry basically originate from the mining of the principal raw material, i.e. bauxite, which in India is produced through open-cast mining. Open-cast mining generates a large amount of dust. Moreover, the ore is subjected to grinding and granulometric sorting which again generates dust. Fresh bauxite is chemically very active and is easily attacked by atmospheric oxygen, moisture and micro-organisms. During rainy season, water which drains over the ore turns acidic and seeps into the water table. Water run-off from the mines thus pollutes both the ground water table as well as surface water.

At the alumina refining stage, environmental problems are created by disposal of red mud, which is a waste product of the process of refining alumina from bauxite. Pollutants like coal dust from steam generators, alumina dust from calcining and stacks emissions of SO_2 from refinery and other miscellaneous wastes. Red mud consists of oxides of Al, Fe, Ti and Si as major constituents and oxides of Va, Ga, Ca, Mg, etc. as minor constituents. The residue from aluminium rich liquor is dumped into tanks which generate dust, pollute ground water through seepage, etc. When the ponds are filled, new disposal sites are selected and this land cannot be put to any agricultural use.

The major pollutants released during smelting are the gaseous and particulate fluoride emissions. About 780 m^3 of gases are generated per tonne of alumina from the cryolite, aluminium fluoride, calcium fluoride and sodium fluoride used in the electrolytic process. The airborne fluorides evolving from aluminium cells have deleterious effects on surrounding animal and vegetation life. A list of type of pollution and pollutants in aluminium industry is provided in **table 5.1**.

Table 5.1. Type of Pollution and Pollutants in a typical aluminium plant

Type of pollution	Material produced
Gaseous emissions	Carbon monoxide, carbon dioxide, hydrogen fluoride, sulphur dioxide, carbon disulphide, silicon tetrafluoride, carbon tetrafluoride, hexa fluoroethane.
Solid emissions	Alumina, cryolite, aluminium fluoride, calcium fluoride, carbon, iron oxide.
Liquid effluent	Fluorine compounds, hydrocarbons entrapped water.
Smelter wastes	Spent potlinings, anode butts from prebaked pots, dust from gas cleaning, sludges from cleaning scrubbing water, material from pot skimming, spills.
Paste preparation emissions and wastes	Coke dust, coal dusts fines, hydrocarbon fumes.
Anode baking emissions and wastes	Hydrocarbons, fluorides, sulphur.
Caste house emissions and waste	Fluxing fumes (primarily aluminium and chloride) trace fluorine, sulphur dioxide.
Ancillary operation emissions and wastes	Dust from bulk material handling, demolition of old pots and cleaning of prebaked anode butts to recover carbon.

Source: DSIR report on aluminium industry

5.2 Environmental standards

Standards to be followed for environment pollution control in the manufacturing units are laid down by respective state pollution control boards. However, the norms/standards applicable to aluminium industry as prescribed by Central Pollution Control Board (CPCB) is given in **table 5.2**.

According to CPCB report titled 'Implementation status of the pollution control measures in major polluting industries' in March 1995, two aluminium units - INDAL's unit at Orissa and HINDALCO - do not have adequate facilities to comply with the pollution control standards.

5.3 Environment pollution control measures

Most of the Indian smelters have provided gas cleaning installations to clean the cell gases before release to the atmosphere through stack. BALCO has installed wet scrubbing facilities for gas cleaning while HINDALCO has installed dry scrubbing for its smelters. Worldwide dry scrubbing is preferred because of high efficiency of fluoride and dust removal, low capital and operating costs. NALCO has put up latest dry absorption system for gas cleaning which not only minimises discharge of harmful emissions and recovers expensive fluoride salts but also ensures better working conditions inside the cell rooms.

Table 5.2. CPCB norms/standards for environment pollution control

Plant section		Parameter	Standards
Alumina plant			
(a)	Raw material handling	Primary and secondary crushers	150 mg/Nm^3
(b)	Precipitation area - Calcination	Particulate matter	250 mg/Nm^3
		CO	1% max
		Stack height	H = 14 (Q)$^{0.3}$*
Smelter plant			
(a)	Green anode shop	Particulate matter	150 mg/Nm^3
(b)	Anode bake	- do -	150 mg/Nm^3
(c)	Potroom	Total fluoride (F)	0.3 kg/MT of aluminium
			150mg/Nm^3
		Particulate matter	
		Total fluoride (F) - VSS	4.7 kg/MT of aluminium produced
			6.0 kg/MT
		- HSS	2.5 kg/MT
		- PBSW	H = 14 (Q)$^{0.3}$*
		- Stack height	

* Where Q is emission rate of SO_2 in kg/hr and H is stack height in meters.

Note: VSS - Vertical Stud Soderburg
HSS - Horizontal Stud Soderberg
PBSW- Prebaked Side Worked
PBCW- Prebaked Centre Worked

Measures are taken by all the units to avoid pollution due to disposal of mud. Thickeners in combination with filters are in use for thickening and washing of red mud. There are several methods of mud disposal system namely conventional red mud ponds, dry disposal system, disposal in sea and bauxite mined out areas.

CHAPTER 6

Conclusion

The aluminium industry in India is highly concentrated, with just five players accounting for the entire production capacity of 6,10,000 tonnes per annum. Aluminium production is a highly energy intensive process with energy accounting for nearly 40% of the production cost. Electricity, coal and fuel oil are the major forms of energy used by the sector, with electricity accounting for 80% of the total energy use. Based on 1994-95 figures, total energy consumed by all primary producers in the country is estimated to be 30.1 Gcal. It is analysed that with a co-ordinated approach on all fronts, energy saving in the range of 15-20% of the total energy use, can be achieved.

The performance of most of the plants on energy front is good as actual specific energy consumption is better than the design norms. Also there are only five manufacturers making the chances of replicability for any energy conservation measures very limited. A comparative assessment of the aluminium sector with the remaining eleven industry sectors covered under the present study suggests that aluminium is not an ideal candidate for the subsequent phases of ESP project. However, some selected details of the five aluminium plants are presented in Annexure-1 at the end.

The following organisation is actively involved in research & development activities in aluminium sector

Jawaharlal Nehru Aluminium Research Development
and Design Centre (J.N.A.R.D.D.C.)
Nagpur - 440 023

ANNEXURE 1

Plant data

1. BALCO

Name and address of the Company	Bharat Aluminium Company Ltd. P.O. Balco Township, Korba (M.P.) Pin - 495684 Phone :- 07780-22008 Fax :- 07780-21870
Year of commissioning	1975
Installed capacity (per annum)	
- Alumina	2 lakh tonne
- Aluminium	1 lakh tonne
Production	
- Aluminium	0.93 lakh tonne
Specific energy consumption for	
a. Alumina	
- steam (t/t)	3.5
- Electricity (kWh/t)	529
- Fuel Oil (kg/t)	101
b. Aluminium	
- Electricity (kWh/t)	18100

2. HINDALCO

Name and address of the company	Hindalco Industries Ltd. Works - Renukoot Distt - Sonebhadra (U.P.) Pin - 231217

Year of commissioning	1962
Installed capacity (per annum)	
- Alumina	3.50 lakh tonne
- Aluminium	1.50 lakh tonne
Production	
- Aluminium	1.64 lakh tonne
Specific energy consumption for	
a. Alumina	
- steam (t/t)	5
- Electricity (kWh/t)	385
- Fuel Oil (kg/t)	85
b. Aluminium	
- Electricity (kWh/t)	15000

3. NALCO

Name and address of the company	National Aluminium Company Works - Angul Distt - Dhenkanal Orissa
Year of commissioning	1987
Installed capacity (per annum)	
- Alumina	8.00 lakh tonne
- Aluminium	2.18 lakh tonne
Production	
- Aluminium	1.29 lakh tonne

Specific energy consumption for

a. Alumina	
- steam (t/t)	3.2
- Electricity (kWh/t)	380
- Fuel Oil (kg/t)	85
b. Aluminium	
- Electricity (kWh/t)	13700

4. INDAL (Belgaum unit)

Name and address of the company	Indian Aluminium Company Works - Hirakud Orissa
Year of commissioning	1987
Installed capacity (per annum)	
- Alumina	2.37 lakh tonne
- Aluminium	1.17 lakh tonne
Production	
- Aluminium	0.45 lakh tonne

Specific energy consumption for

a. Alumina	
- steam (t/t)	2.4
- Electricity (kWh/t)	250
- Fuel Oil (kg/t)	220
b. Aluminium	
- Electricity (kWh/t)	17000

5. MALCO*

Name and address of the Company	Madras Aluminium Company Works - Mettur Dam TamilNadu	
Year of commissioning	1964	
Installed capacity (per annum)		
-	Alumina	0.50 lakh tonne
-	Aluminium	0.25 lakh tonne

* Plant was not in operation since 1991. Production restarted in 1995-96.

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